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Introduction

The human respiration contains carbon dioxide, bioeffluents, and perhaps virus or bacteria. People may also indulge in activities that produce contaminants, as for example tobacco smoking. For these reasons, the human respiration remains one of the main contributors to contamination of the indoor air. This paper describes the design of a new type of thermal manikin. In a number of experimental series, breathing thermal manikins have been used to investigate the role of the human respiration as a contaminant source in the indoor environment (Bjørn and Nielsen, 1996a, 1996b; Bjørn et.al., 1997). The same manikins were simultaneously used to assess personal exposure to exhaled contaminants. The design of these manikins has been used for air quality studies (Hatton and Awbi, 1998) with the consent of this author. The reason for using a thermal manikin for these purposes - rather than just adding contaminants through e.g. a simple jet – is that complicated interactions take place between respiration flow, thermal boundary layer flows, and thermal plumes. These may be studied in a realistic environment by using full-scale test rooms with life-sized breathing thermal manikins.

Design of breathing thermal manikin

The manikin is intended to simulate a Human Being in full-scale experiments in the sense of a flow obstacle, a heat source, and a contaminant source. Therefore, the following properties are made as realistic as possible, while still trying to keep down costs: External geometry, emissivity, total heat output, temperature distribution, exhalation flow. Since the manikin can inhale as well as exhale, it can also be used to measure contaminant exposure. The manikin consists of a hollow aluminum shell (thickness 1mm) covered with a coat of paint (to ensure correct transmission of radiative energy). The manikin is *not* intended for assessment of thermal comfort, as are some other thermal manikins.

Geometry

The manikin is composed entirely of simple geometrical shapes, thus making it relatively simple and cheap to produce, see figure 1. The surface area is 1.44 m^2. For reasons of comparison, the external geometry of the manikin is designed to be as similar as possible to a thermal manikin from the Technical University of Denmark, which is also in the possession of the Indoor Environmental Engineering group at Aalborg University. The latter manikin is designed for studies of thermal comfort. The geometry of both manikins are as close as possible to a size 38 woman as described in (STU, 1977).

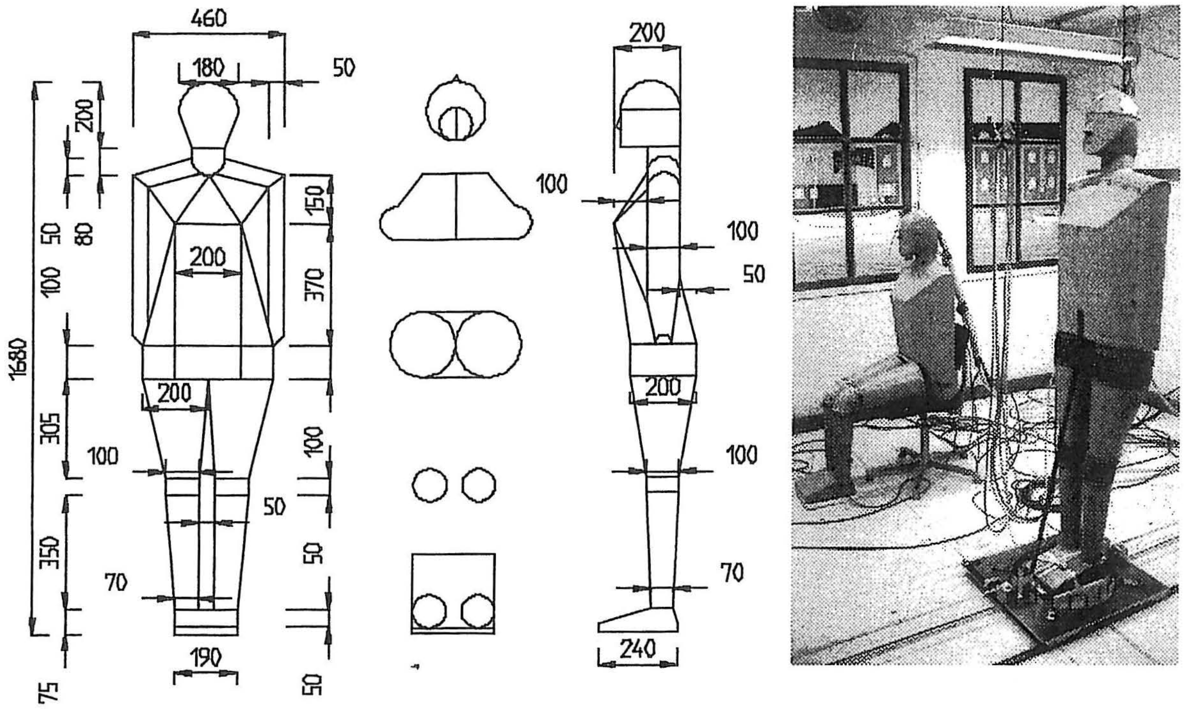

Figure 1: *Left:* Geometry of breathing thermal manikin. *Right:* Two breathing thermal manikins in full-scale test room. In this case, the upright standing manikin is attached to a trolley, which allows studies of the influence of movements.

<u>Internal flow and temperature distribution</u>
The torso of the manikin is divided by an vertical aluminum plate. The legs are separate. The arms are connected to the torso. In this way, the manikin is divided into two separate spaces or "ducts", which are connected through the head and feet of the manikin. Inside it is equipped with two fans (one in each "duct") forcing the air to circulate rapidly, and with 15 m of heating wire distributed evenly throughout the interior of the manikin, thus ensuring an even temperature distribution (approx. ± 1°C at normal heat loads, with a tendency to have warmer head and torso, and colder legs). The convective heat transfer coefficient has been measured to be approx. 4.8 W/°Cm^2, which is consistent with measurements of live persons.

<u>Heat output</u>
The total heat output supplied to the manikin can be controlled between 0 - 400 W. In this way, one is not confined to realistic heat outputs, but can experiment with model conditions. The output supplied to the fans and to the heating wire is measured separately.

<u>Breathing function</u>
The manikin is connected to an artificial "lung" that provides respiration through mouth and/or nose. The artificial lung consists simply of a cylinder with a piston driven by an electric motor. The pulmonary ventilation and respiration frequency can be regulated in a wide range. Pulmonary ventilation for an adult at rest is approx. 6 liters pr. minute, at a respiration frequency of 10-12 breaths pr. minute. The air is exhaled from the nose of the manikin in two jets with direction ca. 45° below vertical, and with an intervening angle of ca. 30°. The figures regarding angle are obtained

from (Hyldgaard, 1994), who has measured this on his own exhalation. No studies have been found of larger populations. The nostrils consist of circular openings with diameter = 12 mm. This is close to the mean cross-sectional area of the nostrils of healthy adults according to (Grymer et.al., 1991). The mouth consists of a circular opening (diameter 12 mm). It is debatable what the cross-sectional area of the mouth should be, since this can obviously vary within a wide range. Some sensitivity studies of this parameter have been carried out by numerical methods in (Bjørn and Nielsen, 1998).

Density of exhaled air.

A simple heating coil heats the air immediately before it enters the manikin. Due to the oscillating airflow, the exhalation temperature is not completely constant, but varies approx. ±1°C. This oscillatory behavior is quite realistic. The mean exhalation temperature depends mainly on inhalation (i.e. ambient) temperature (P.Höppe, 1981). At an ambient temperature of 20, the mean temperature is approx. 32°C for exhalation through the nose, 34°C for exhalation through the mouth. Exhaled air has a different molecular composition compared to atmospheric air. This has some consequences to the density of the air, which in turn will affect the buoyancy. In full-scale experiments, one will usually add a tracer gas to simulate contaminant (e.g. N_2O). Ideally, the exhaled air should also be saturated with water vapour. This may, however, have some unfortunate practical consequences, as some gas analyzers (e.g. Binos 1.2, which was used in some experiments) are sensitive to changes in relative humidity. If the exhaled air is not saturated, the temperature should be corrected. An example is shown in figure 2.

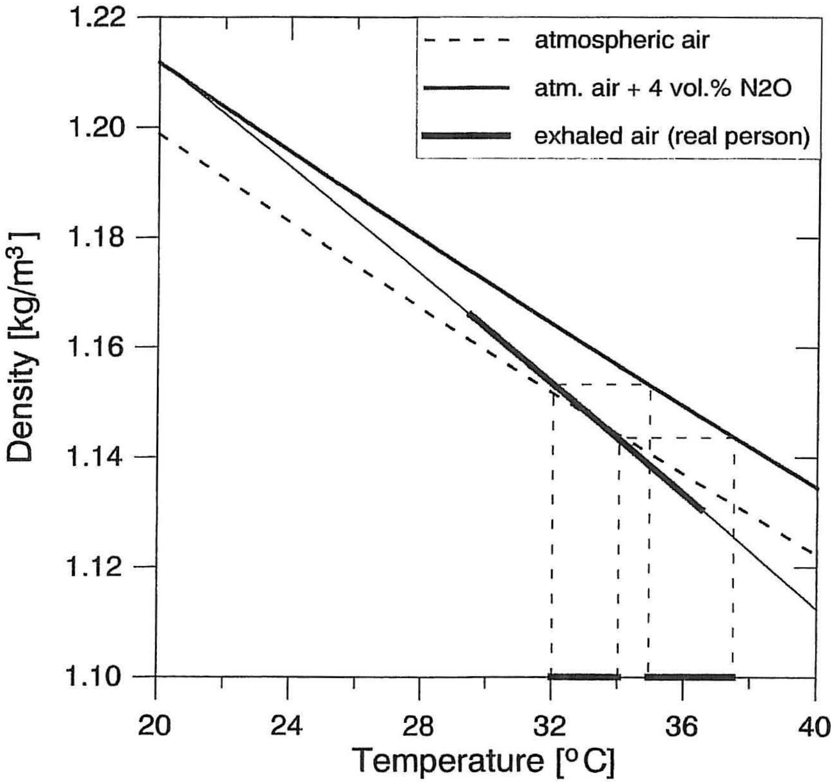

Figure 2: Influence of water vapour on density of exhaled air. Example: If one wishes to simulate exhaled air at 32°C using dry atmospheric air containing tracer gas N_2O, air temperature in experiments should be 35°C. (Pressure = 101325 Pa)

Discussion

A main problem in simulating respiration, and especially in simulating the exhalation flow, is the lack of empirical data from living persons. Extensive studies have been made by members of the medical profession, but almost without exception, the focus of these studies are on the internal workings of the respiratory system, often in connection with illnesses of some kind. This problem should be addressed in future research. In some instances – e.g. coughing and sneezing in hospital environments – it is probably important to simulate the movement of particles emitted from the exhalation. This subject also needs further attention. In most normal situations, people will move around more or less. Some preliminary studies have been made on this issue (Bjørn et.al, 1997). Much more can be done, however. A future objective of this worker is to include physical movements in manikin design: the breathing and moving thermal manikin.

Acknowledgement

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